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Influence of Aging Temperature During Artificial Aging Process on Aluminium Alloy to the Mechanical Properties

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Abstract*—The aging process is a hardening process that aims to change the physical properties and mechanical properties of the material according to needs. This process is carried out by holding the heating process at a certain temperature for a certain period of time. Aluminium alloys have good mechanical properties. One way to improve the mechanical properties of a material is by hardening process. This aging process is one example of the hardening process. In this study, an artificial aging process was carried out on aluminium 6061 alloys. Analysis was carried out on the effect of aging temperature during the artificial aging process. Temperature variations used are 100, 125, 150, 175, 200ºC. The holding time is 1 hour. At the beginning of the process, heating with a heat treatment solution was carried out at 300ºC for 1 hour. Then quenching with water media. The next work process, heat treatment is carried out with the variations mentioned above. The last step is to do quenching again. Analysis of the mechanism is carried out on impact strength, hardness value and microstructure. The results of the analysis show that the best aging temperature range during the artificial aging process in 6061 aluminium alloys is at 150 to 200ºC. In this study, the best impact strength was produced at an aging temperature of 200° C, the best hardness value at an aging temperature of 150° C and a microstructure that contained the least precipitations at a temperature of 200°C.

Keywords*—Aging Processm Artificial Aging, Aluminium 6061, Temperature, Heat Treatment.

I. INTRODUCTION

Aluminium 6061 is an aluminium alloy that is generally applied to automotive and construction equipment. This alloy has advantages such as corrosion resistance, thermal conductivity, good toughness, and good welding properties so that many advanced industries use this material as the main material for designing tools and construction. Not only that, Aluminium 6061 is often used to apply sub-zero temperatures, LNG tanks, low-pressure vessels, marine equipment, drilling rigs, building frame structures, construction of aircraft structures such as wings and airframe, canoes, car trains, and shipbuilding cruise.

One process to improve the mechanical properties of a material is the heat treatment process. This process includes the hardening process. Artificial aging process is an example of hardening process. There are several studies that analyze the effects of artificial aging on aluminium alloys, one of which is Westermann [1]. This researcher has conducted research on work-hardening and ductility on AA 6060 Aluminium alloy. The results of his research explain that there is an influence of the thermomechanical process during the artificial aging process on the stress-strain behavior and the tensile failure strain of the alloy. Katharina also conducted research on artificial aging, only focusing more on the influence of quench rate on age hardening behavior on aluminium AA 6060 [2].

In this study, the analysis focused on the effect of aging temperature during artificial aging processes on mechanical properties in 6061 aluminium alloys. The mechanical properties analyzed were impact strength, hardness value and microstructure. It is expected that in the research obtained aging temperature range which has the best mechanical properties.

II. EXPERIMENTAL PROCEDURES

A. Material and artificial aging process

The material used was aluminium alloy with 0.01% Zn, 0.99% Mg, 0.31% Cu, 0.08% Mn, 0.25% Fe, 0.66% Si and Cr 0.16%. The specimen manufacturing process aimed to be used when mechanical testing. The specimen dimension was 55 x 10 x 10 mm (based on ASTM E23-07a), with a 2 mm indentation, 0.25 mm radius and 45º angle. The initial process before the artificial aging process was done by heating the solid solution at 300ºC for 1 hour. Furthermore, queching has been done using water media (room temperature). After cooling process, the artificial aging process would have begun. The temperature variations used during the artificial aging process was 100, 125, 150, 175, 200°C. The holding time was 1 hour. Every iteration has been carried out three times. Then the cooling process with queching medium water (room temperature) was carried out.

B. Mechanical testing

After the artificial aging process was complete, then mechanical testing was carried out. In this study, testing was conducted to determine the value of impact strength, hardness value and microstructure. The impact testing method used was the charpy method. From the results of the impact strength test could be known the material ability to received impact loads after experiencing an artificial aging process. For hardness values obtained from Vickers Hardness machine. As for the microstructure, the number of prespitations that occured after the artificial aging process is seen.

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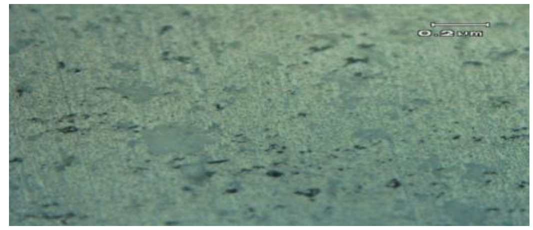
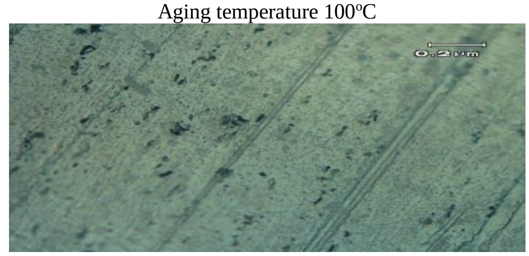
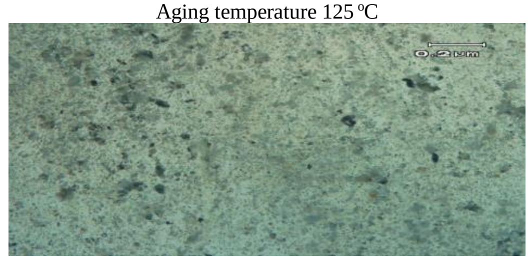
TABLE 1.
THE ENERGY AND IMPACT STRENGTH VALUE AFTER THE ARTIFICIAL AGING PROCESS

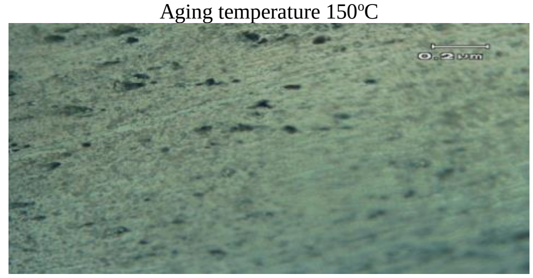
Temperature Aging	Specimen	Angle (β)	A	Impact Testing	
				E (Joule)	IS (Joule/mm^2)
100°C	1	109	80	336.66	4.11
	2	111	80	311.16	3.82
	3	113	80	286.15	3.53
	Average			311.26	3.82
125°C	1	117	80	237.12	2.84
	2	120	80	201.42	2.45
	3	120	80	201.42	1.47
	Average			213.29	2.54
150°C	1	120	80	201.42	2.45
	2	122	80	178.28	2.15
	3	125	80	144.45	1.76
	Average			174.65	2.05
175°C	1	101	80	441.10	5.39
	2	107	80	362.35	4.51
	3	109	80	336.66	4.11
	Average			380.00	4.60
200°C	1	101	80	441.10	5.39
	2	103	80	414.62	5.09
	3	107	80	362.35	4.51
	Average			405.99	5.00

Where:
E = Impact of Energy
IS = Strength of Impact


Aging temperature 100ºC


Aging temperature 125 ºC


Aging temperature 150ºC


Aging temperature 175ºC

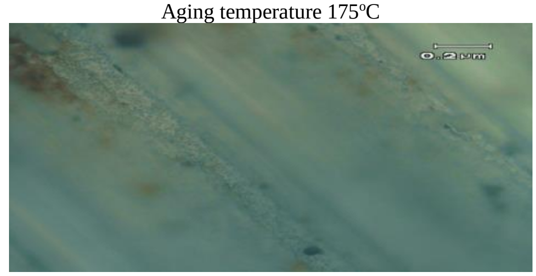

Aging temperature 200ºC

Figure 1. Microstructure after artificial aging process

III. RESULT AND DISCUSSION

A. *Impact Testing*

In this study, impact testing has been done using a charpy impact type HT-8041A machine. The weight (W) of the pendulum on this machine was 131.7N. The center of gravity from the pendulum to 0 (L) was 0.60m. the starting angle (α) was 140 °.This test aimed to get the value of energy and impact strength, so that it could be known the effect of aging temperature variation on energy and impact strength. From the impact test, the data angle (β) was obtained. This angle data was used to investigate the impact of energy and impact strength. Data obtained from impact tests were shown in the Table 1.

Based on the data, showed that the energy and impact strength value decreased at a temperature range of 100-150ºC, but when the aging temperature was increased, the energy and impact strength value increased. At a aging temperature of 100ºC, the energy value of 311.26 joules and impact strength was 3.82 joule/mm^2. When the aging temperature increases to 125ºC, the value of energy and impact strength value decreased to 213.29 joules and 2.54 joules/mm^2. The highest reduction in impact energy and impact strength was obtained when the aging temperature was increased to 150ºC, ie 174.65 joules and 2.05 joules/mm^2. When the aging temperature increases at 175ºC, the energy and impact strength value increased to 380 joules and 4.60 joules/mm^2 from the aging temperature of 150ºC. And when at 200ºC the energy value and impact strength also increased to 405.99 joules and 5 joules/mm^2. The decrease in energy value and impact strength at a temperature range of 100-200ºC was likely due to the amount of precipitation that occurs. This precipitation had characteristics that are not good, including fractures, shiny and grained. This had an impact on the energy value and impact strength which showed the material became more fragile.

B. *Surface Observation*

Metallographic testing was used to see Aluminium microstructure using an optical microscope. Before being observed with an optical microscope, the test specimen was etched using a Keller reagent solution. The change in microstructure is in the form of qualitative data which is used to support data from the value of changes in hardness and impact strength due to aging temperature variations.

The following is a presentation of the microstructure of the 6061 aluminium alloy after the artificial aging process.

Figure 1 showed that the increasing of aging temperature (100-150C) it mean the more precipitates were formed and the more evenly spread the distribution. The number of precipitates decreased, when the aging temperature increased (175-200°C), at an aging temperature of 200°C there was almost no precipitation.

TABLE 2.
HARDNESS VALUE AFTER THE ARTIFICIAL AGING PROCESS

Aging temperature	Hardness Value	
	Value of Hardness (HVN)	Average (HVN)
100°C	50.3 49.5 49.5	49.8
125°C	57.6 57.2 56.9	57.2
150°C	81.3 81.3 79.7	80.8
175°C	68.5 68.1 67.7	68.1
200°C	51.6 51.4 51.1	51.4

Microstructure changes occured due to heat treatment. With increasing aging temperature gave a difference in the form of microstructure. Microstructural changes occured because the heat treatment was gave the atom the opportunity to move and place its location, so that the atomic structure became more regular. With the addition of aging time, precipitates became more regular and appear denser. The microstructure seems to be arranged along with the aging process that is increasing because the GP Zone that is formed continues to grow in terms of size, and number. An increase in temperature causes the number of precipitates to increase. This causes the distance between the precipitate particles to be closer. These precipitates acted as a barrier to dislocations which showed that material is increasingly difficult.

However, at an aging temperature of 200°C the microstructure was no better than the 175°C aging temperature. When the temperature of aging increases, precipitates growed and multiply. When the aging temperature reaches the peak aging limit, metastable precipitates were formed. When it came to this temperature, and was raised again, the precipitate formed would join and become coherent with the matrix [3][4]. So that in the hardness testing at an aging temperature of 150°C the most optimal results were obtained, while at a temperature of 200°C the hardness was lower than at a temperature of 175°C.

C. Hardness Measurement

Hardness test was done after the specimen in the aging process. The modified variables were the aging process temperature, but holding time was fixed. In this hardness testing was done by using Vickers hardness. This hardness test aimed to determine the effect of aging temperature variation on the value of aluminium hardness 6061.

The following data obtained from the hardness test after the specimens processed aging, then the specimens in the hardness was tested to get the information of hardness with the variation of aging temperature and will be shown in the Table 2. From hardness test result, could be obtained the average value of hardness from the specimens that had been given aging process at temperatures 100, 125, 150, 175, and 200°C. This data was used to determine the value of hardness. The average value of hardness from the test results can be seen from the following graph.

When aging temperature 100°C, the hardness of the specimen was 49.8 HVN. When the aging temperature increased to 125°C, the value of hardness rose with a value of 57.2 HVN. The highest value in hardness obtained when the aging temperature increases to 150°C which was 80.8 HVN. When the aging temperature raised at 175°C, the hardness value drops to 68.1 HVN from the aging temperature of 150°C whose value was 80.8 HVN. And at a temperature of 200°C, the hardness value becomes 51.4 HVN.

The obtained data from the 6061 aluminium hardness test showed that the variation of aging temperature has an effect on hardness value. The higher the temperature to the limit specified, then the aluminium hardness would increased as well. Aging at the temperature of 100°C (natural aging) undergoes first-stage hardening which had a zone phase [GP 1]. Aging at 125°C produced greater hardness than aging at a temperature of 100°C, and a 150°C aging temperature greater than 125°C, even though the aging temperature of 150°C was still included in the [GP 1] zone phase. It was because at the temperature of 150°C was the end of the first phase hardening and the maximum zone of the [GP 1] phase. The highest hardness obtained at the 150°C temperature of aging and at 80.8 HVN, which was still a peak aged temperature region. In this hardness, the aluminium was in the zone [GP 2] or Phase θ which included second stage hardening after from zone [GP 1]. When the aging temperature is 175°C, the value of the hardness originally continued to rise from temperature 100°C up to 150°C turned down. It was because after going through the phase zone [GP 2] or Phase θ when the temperature was raised again then the phase will turn into phase θ. The formation of the θ phase made the aluminium soft.

The result of microstructural observation showed that the increased of hardness of aluminium 6061 from temperature 100-150°C characterized by growing more precipitates. The larger precipitates and the increasing amounts caused the distances between precipitate particles to become denser [4][5]. This solid precipitate acted as a barrier which causes the dislocation to shift to be more difficult when there was deformation in the alloy. It appeared from the microstructure that the value of hardness decreased when aging at 175^{o}C due to the amount of precipitate being dropped. It was because of the incorporation or hardening of the precipitate which becomes coherent with the matrix [5].

IV. CONCLUSION

Based on the analysis and discussion showed that there were influence on the mechanical properties of materials that have undergone an artificial aging process. for impact testing, the peak temperature which has the best impact strength value is 150oC. above that temperature has decreased the value of impact strength. this is supported by observations of microstructure. at an aging temperature of 150oC the amount of presipitate is the most than the others. so does hardness measurement. at this temperature has the highest hardness value compared to others.

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